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state that the attached documents are a true and complete translation to the best of my knowledge of Japanese Patent Application No. 212190/1999

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[Name of Document] SPECIFICATION

[Title of the Invention] OPTICAL FILTER

[Claims]

[Claim 1] An optical filter comprising:

a main optical line propagating light from an optical entrance end to an optical exit end;

a first auxiliary optical line optically coupled to the main optical line via a first optical coupler and a second optical coupler and constituting a first Mach-Zehnder interferometer together with the main optical line, the first optical coupler, and the second optical coupler;

a second auxiliary optical line optically coupled to the main optical line via a third optical coupler and a fourth optical coupler and constituting a second Mach-Zehnder interferometer together with the main optical line, the third optical coupler, and the fourth optical coupler;

a first temperature regulating device for adjusting the temperature of both or at least one of the main optical line and the first auxiliary optical line, which are positioned between the first optical coupler and the second optical coupler; and

a second temperature regulating device for adjusting the temperature of both or at least one of the main optical line and the second auxiliary optical line, which are positioned between the third optical coupler and the fourth optical coupler,

wherein, by the temperature adjustment effected by the first temperature regulating device and the second temperature regulating device, the loss of light between the optical entrance end and the

optical exit end is kept substantially constant in a predetermined wavelength in a predetermined wavelength band and the slope of loss of the light with respect to the wavelength in the wavelength is set.

[Claim 2] An optical filter as set forth to claim 1, wherein the first temperature regulating device adjusts the temperature of any one of the main optical line and the first auxiliary optical line, which are positioned between the first optical coupler and the second optical coupler, and wherein the second temperature regulating device adjusts the temperature of any one of the main optical line and the second auxiliary optical line, which are positioned between the third optical coupler and the fourth optical coupler.

[Claim 3] An optical filter as set forth to claim 1, wherein the first temperature regulating device adjusts the temperatures of both of the main optical line and the first auxiliary optical line, which are positioned between the first optical coupler and the second optical coupler, and wherein the second temperature regulating device adjusts the temperatures of both of the main optical line and the second auxiliary optical line, which are positioned between the third optical coupler and the fourth optical coupler.

[Claim 4] An optical filter as set forth to claim 1, wherein the wavelength band includes a band of from 1535 nm to 1565 nm.

[Claim 5] An optical filter as set forth to claim 1, wherein the wavelength band includes a band of from 1575 nm to 1605 nm.

[Claim 6] An optical filter as set forth to claim 4 or claim 5, wherein the absolute value of the slope of loss can be changed at least within the range of from 0 dB/30 nm to 5 dB/30 nm.

[Claim 7] An optical filter as set forth to claim 4 or claim 5, wherein the absolute value of the slope of loss can be changed at least within the range of from 0 dB/30 nm to 10 dB/30 nm.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to an optical filter applicable to a gain equalizer for equalizing the gains of signal light in optical amplifiers, and the like.

[0002]

[Related Art]

An optical amplifier includes an optical waveguide doped with a fluorescent material which can be excited by pumping light and amplifies optical signal, and a pumping light source for supplying the pumping light to the optical waveguide, and is disposed in a repeater station in an optical transmission system or the like. In particular, it is important for the optical amplifier employed in a wavelength multiplex transmission system transmitting signal light having a plurality of wavelengths to not only collectively amplify the signal light having the plurality of wavelengths with gains identical to each other, but also make the power of the individual signal light having the plurality of wavelengths a predetermined target value to output it. Therefore, in order to equalize the amplification gain of the signal light in such an optical amplifier, an optical filter having a loss spectrum with a form identical to that of the gain spectrum in the signal wavelength band has been in use.

[0003]

For example, a technique aimed at flattening the gain of an optical amplifier by use of an optical filter employing a Mach-Zehnder interferometer is disclosed in the document 1, K. Inoue, et al., "Tunable Gain Equalization Using a Mach-Zehnder Optical Filter in Multistage Fiber Amplifiers," IEEE Photonics Technology Letters, Vol. 3, No. 8, pp. 718-720 (1991). Also, an optical filter in which two optical filters described in the above-mentioned document 1 are cascaded to each other is disclosed in the document 2, H. Toba, et al., "Demonstration of Optical FDM Based Self-Healing Ring Network Employing Arrayed-Waveguide-Grating ADM Filters and EDFAs," Proceedings of ECOC'94, pp. 263-266 (1994). Further, an optical filter including a Faraday rotator adapted to alter the amount of rotation of polarizing azimuth of light, a birefringent plate, two birefringent wedge-shaped members, and a lens system is disclosed in the document 3, T. Naito, et al., "Active Gain Slope Compensation in Large-Capacity, Long-Haul WDM Transmission System," Proceedings of OAA'98, WC5, pp. 36-39 (1999).

[0004]

[Problems to be Solved by the Invention]

However, if the power of signal light entering an optical amplifier fluctuates due to the fact that the loss in an optical transmission line positioned in front of the optical amplifier fluctuates for some reason in the technique disclosed in the above-mentioned document 1, then the amplification gain for the signal light in the optical amplifier has to be changed in order for the signal light emitted from the optical amplifier to keep its power

constant. If the gain is changed, then the wavelength dependence of gain, that is, a gain slope fluctuates, so that the gain flatness of the optical amplifier is lost, whereby the signal light having a plurality of wavelengths emitted from the optical amplifier has a deviation in the power.

[0005]

In the technique disclosed in the above-mentioned document 2, in order to deal with problems such as those mentioned above, the respective temperatures of the optical couplers and branched optical lines in each Mach-Zehnder interferometer constituting the optical filter are adjusted according to the power of incident signal light to adjust the slope of loss spectrum of the optical filter, whereby the fluctuation in gain slope accompanying the power fluctuation of the incident signal light is compensated. However, when the slope of loss spectrum in the optical filter is changed according to the power of the incident signal light, the loss level in the signal light wavelength band fluctuates, whereby the S/N ratio of amplified signal light outputted from the optical amplifier fluctuates and deteriorates. Also, the number of heaters provided for adjusting the slope of loss spectrum in the optical filter is 6, which is relatively large, whereby the slope control is complicated.

[0006]

In the technique disclosed in the above-mentioned document 3, the amount of rotation of the polarizing azimuth of light in the Faraday rotator is adjusted such that the deviation of the power of the signal light having a plurality of wavelengths is made smaller, whereby the slope of loss of the optical filter is adjusted and thus

the deviation of the power of the signal light having the plurality of wavelengths is reduced. Unlike the technique disclosed in the above-mentioned document 2, even when the slope of loss in this optical filter is changed, the loss of the predetermined center wavelength in the signal light wavelength band is kept at a nearly constant level. However, since the number of components is large in this optical filter, not only its configuration is complicated, but also its optical axis adjustment is quite difficult at the time of assembling.

[0007]

In order to eliminate problems such as those mentioned above, the present invention has been made, and it is the object of the present invention to provide an optical filter which is suitably used as a gain equalizer or the like in an optical amplifier, has a simple structure, and can easily control the slope of loss.

[0008]

[Means for Solving the Problems]

An optical filter in accordance with the present invention includes: a main optical line propagating light from an optical entrance end to an optical exit end; a first auxiliary optical line optically coupled to the main optical line via a first optical coupler and a second optical coupler and constituting a first Mach-Zehnder interferometer together with the main optical line, the first optical coupler, and the second optical coupler; a second auxiliary optical line optically coupled to the main optical line via a third optical coupler and a fourth optical coupler and constituting a second Mach-Zehnder interferometer together with the main optical line,

the third optical coupler, and the fourth optical coupler; a first temperature regulating device for adjusting the temperature of both or at least one of the main optical line and the first auxiliary optical line, which are positioned between the first optical coupler and the second optical coupler; and a second temperature regulating device for adjusting the temperature of both or at least one of the main optical line and the second auxiliary optical line, which are positioned between the third optical coupler and the fourth optical coupler, wherein, by the temperature adjustment effected by the first temperature regulating device and the second temperature regulating device, the loss of light between the optical entrance end and the optical exit end is kept substantially constant in a predetermined wavelength in a predetermined wavelength band and the slope of loss of the light with respect to the wavelength in the wavelength band is set.

[0009]

In the optical filter in accordance with the present invention, the first Mach-Zehnder interferometer is constituted by the main optical line, the first auxiliary optical line, the first optical coupler, and the second optical coupler; and the second Mach-Zehnder interferometer is constituted by the main optical line, the second auxiliary optical line, the third optical coupler, and the fourth optical coupler. The first and second Mach-Zehnder interferometers are cascaded to each other while sharing the main optical line. The temperature of both or at least one of the main optical line and the first auxiliary optical line, which are positioned between the first optical coupler and the second optical coupler, is adjusted

by the first temperature regulating device, and the temperature of both or at least one of the main optical line and the second auxiliary optical line, which are positioned between the third optical coupler and the fourth optical coupler, is adjusted by the second temperature regulating device. Then, the transmitting characteristics of the first and second Mach-Zehnder interferometer are adjusted by the temperature adjustment effected by the first and second temperature regulating devices, and the loss of light between the light entrance end and the light exit end is kept substantially constant in the predetermined wavelength in the predetermined wavelength band, and the slope of loss of the light with respect to the wavelength in the wavelength band is set. In this manner, the optical filter in accordance with the present invention has a simple structure, can easily control the slope of loss, and thus is suitably used as a gain equalizer or the like in an optical amplifier, for example.

[0010]

The optical filter in accordance with the present invention is characterized in that the first temperature regulating device adjusts the temperature of any one of the main optical line and the first auxiliary optical line, which are positioned between the first optical coupler and the second optical coupler, and that the second temperature regulating device adjusts the temperature of any one of the main optical line and the second auxiliary optical line, which are positioned between the third optical coupler and the fourth optical coupler. In this case, it is only necessary that one piece of heater, Peltier device, or the like be provided as the first temperature regulating device, and that one piece of heater, Peltier device,

or the like be provided as the second temperature regulating device, whereby a simpler configuration can be realized. In particular, in the case where the temperature of the main optical line positioned between the first optical coupler and the second optical coupler is adjusted while the temperature of the second auxiliary optical line positioned between the third optical coupler and the fourth optical coupler is adjusted, both of them can be subjected to the same temperature adjustment (for example, temperature is raised or lowered in both of them), whereby the temperature adjustment can be further easily realized.

[0011]

The optical filter in accordance with the present invention is characterized in that the first temperature regulating device adjusts the temperatures of both of the main optical line and the first auxiliary optical line, which are positioned between the first optical coupler and the second optical coupler, and that the second temperature regulating device adjusts the temperatures of both of the main optical line and the second auxiliary optical line, which are positioned between the third optical coupler and the fourth optical coupler. In this case, two pieces of heaters, Peltier devices, or the like are provided as the first temperature regulating device, whereas two pieces of heaters, Peltier devices, or the like are provided as the second temperature regulating device. Here, when no temperature adjustment is carried out by means of any of the four heaters, the slope of loss can be set to a predetermined value (for example, the value is 0). Also, the slope of loss can be set not only positive but also negative by temperature adjustment carried

out by two heaters or the like selected from the four heaters or the like alone. As a consequence, it is preferable in that power consumption is low.

[0012]

The optical filter in accordance with the present invention, it is preferable that the wavelength band includes a band of from 1535 nm to 1565 nm, or a band of 1575 nm to 1605 nm. Preferably, the absolute value of the slope of loss can be changed at least within the range of from 0 dB/30 nm to 5 dB/30 nm, and more preferably, the absolute value of the slope of loss can be changed at least within the range of from 0 dB/30 nm to 10 dB/30 nm. In these cases, the optical filter in accordance with the present invention is suitably used as a gain equalizer for equalizing the gain characteristics of an optical amplifier disposed in a repeater station or the like in an optical transmission system transmitting the signal light having a plurality of wavelengths in a wavelength of 1.55 μm and a wavelength of 1.59 μm.

[0013]

[Description of the Preferred Embodiments of the Invention]

In the following, preferred embodiments in accordance with the present invention will be described in detail with reference to the accompanying drawings. In the description of the drawings, like reference characters will be attached to like parts and their overlapping descriptions will be omitted.

[0014]

(First Preferred Embodiment)

First, the first preferred embodiment of the optical filter

in accordance with the present invention will be described. Fig. 1 is a view showing the configuration of the optical filter in accordance with the first preferred embodiment. The optical filter 1 in accordance with the present preferred embodiment is a planar optical waveguide circuit disposed on a substrate 10, and includes a main optical line 20, a first auxiliary optical line 21, a second auxiliary optical line 22, a heater 51 as a first temperature regulating device, and a heater 53 as a second temperature regulating device.

[0015]

The main optical line 20 is an optical line disposed between an optical entrance end 11 positioned at one end face of the substrate 10 and an optical exit end 12 positioned at the other end face thereof. Successively disposed from the optical entrance end 11 to the optical exit end 12 are a first optical coupler 31, a second optical coupler 32, a third optical coupler 33, and a fourth optical coupler 34. The main optical line 20 and the first auxiliary optical line 21 are optically coupled to each other by way of the first optical coupler 31 and the second optical coupler 32; and the main optical line 20, the first auxiliary optical line 21, the first optical coupler 31, and the second optical coupler 32 constitute a first Mach-Zehnder interferometer 41. On the other hand, the main optical line 20 and the second auxiliary optical line 22 are optically coupled to each other by way of the third optical coupler 33 and the fourth optical coupler 34; and the main optical line 20, the second auxiliary optical line 22, the third optical coupler 33, and the fourth optical coupler 34 constitute a second Mach-Zehnder interferometer 42. Here, the first Mach-Zehnder interferometers 41 and the second Mach-Zehnder

interferometers 42 are cascaded to each other while sharing the main optical line 20.

[0016]

The heater 51 is disposed on the main optical line 20 positioned between the first optical coupler 31 and the second optical coupler 32. The heater 51 adjusts the temperature of the main optical line 20 to adjust the optical path length difference between the main optical line 20 and the first auxiliary optical line 21 in the first Mach-Zehnder interferometer 41, whereby the transmission characteristic of the first Mach-Zehnder interferometer 41 is adjusted. Also, the heater 53 is disposed on the second auxiliary optical line 22 positioned between the third optical coupler 33 and the fourth optical coupler 34. The heater 53 regulates the temperature of the second auxiliary optical line 22 to adjust the optical path length difference between the main optical line 20 and the second auxiliary optical line 22 in the second Mach-Zehnder interferometer 42, whereby the transmission characteristic of the second Mach-Zehnder interferometer 42 is adjusted.

[0017]

In this optical filter 1, the loss spectrum $L(\lambda)$ of light entering the optical entrance end 11 and propagating through the main optical line 20 toward the optical exit end 12 follows both of the transmission characteristic $T1(\lambda)$ of the first Mach-Zehnder interferometer 41 based on the optical coupling between the main optical line 20 and the first auxiliary optical line 21 by means of the first optical coupler 31 and the second optical coupler 32, and the transmission characteristic $T2(\lambda)$ of the second Mach-Zehnder

interferometer 42 based on the optical coupling between the main optical line 20 and the second auxiliary optical line 22 by means of the third optical coupler 33 and the fourth optical coupler 34.

[0018]

In general, the transmission characteristic $T(\lambda)$ of a Mach-Zehnder interferometer is represented by the following formula:

[Formula 1]

$$T(\lambda)=1-A\cdot\sin^2[2\pi(\lambda-\lambda_0)/\Delta\lambda+\Delta\phi] \qquad (1)$$

Here, λ is the wavelength of light. Also, A, λ_0, $\Delta\lambda$ are constants determined by the structural parameters of the Mach-Zehnder interferometer. Also, $\Delta\phi$ is the phase value which can be set by temperature adjustment. Then, the loss spectrum $L(\lambda)$ of the optical filter 1 is represented by the following formula:

[Formula 2]

$$L(\lambda)=-10\cdot\log[T1(\lambda)\cdot T2(\lambda)] \qquad (2)$$

Also, the slope $S(\lambda)$ of the loss of the optical filter 1 is represented by the following formula:

[Formula 3]

$$S(\lambda)=dL(\lambda)/d\lambda \qquad (3)$$

Here, the unit for the loss $L(\lambda)$ of the optical filter 1 is dB.

[0019]

In the optical filter 1, the respective values of constants A, λ_0, and $\Delta\lambda$ of each of the first Mach-Zehnder interferometer 41 and the second Mach-Zehnder interferometer 42 are appropriately designed, whereby the loss $L(\lambda_1)$ at a predetermined wavelength λ_1 in a predetermined wavelength band is kept substantially constant

and the value of phase value $\Delta\phi$ is set by the temperature regulation by way of the heaters 51, 53, and thus the loss spectrum $L(\lambda)$ and the slope $S(\lambda)$ of the loss spectrum in the wavelength band are set. As described in the following preferred embodiments, the slope $S(\lambda)$ of loss of the optical filter 1 does not depend much on wavelength λ, that is, the loss $L(\lambda)$ of the optical filter 1 is excellent in its linearity with respect to the wavelength λ.

[0020]

Next, the first preferred embodiment of the optical filter 1 in accordance with the present preferred embodiment will be described. The first preferred embodiment was an optical filter having a wavelength band of 1.55 μm, that is, from 1535 nm to 1565 nm, a center wavelength of 1550 nm, and a maximum absolute value of 5 dB/30 nm in the slope of loss. In the first preferred embodiment, in the first Mach-Zehnder interferometer 41, the value of A is 0.6, the value of λ_0 was 1550 nm, and the value of $\Delta\lambda$ was 200 nm. Also, in the second Mach-Zehnder interferometer 42, the value of A was 0.5, the value of λ_0 was 1600 nm, and the value of $\Delta\lambda$ was 200 nm. Then, the respective temperatures of the main optical line 20 in the first Mach-Zehnder interferometer 41 and the second auxiliary optical line 22 in the second Mach-Zehnder interferometer 42 were adjusted by the heaters 51, 53, to make the respective values of phase value $\Delta\phi$ of the Mach-Zehnder interferometers 41, 42 have the same absolute value with polarities opposite to each other to change the phase value $\Delta\phi$ within the range of from 0 rad to 0.595 rad.

[0021]

Fig. 2 shows respective loss spectra with respect the phase

value $\Delta\phi$ in the optical filter on accordance with the first preferred embodiment. As is clear from this graph, near the center wavelength of 1550 nm in the wavelength band of from 1535 nm to 1565 nm, loss is from 2.73 dB to 3.01 dB and thus is substantially constant. Also, it is seen that the slope of loss spectra can be set within the range of from 0 dB/30 nm to 5.05 dB/30 nm in the above-mentioned wavelength band. Also, the maximum value of a deviation from a straight line passing a point yielding a loss of 2.89 dB (at the center wavelength of 1550 nm) is ±0.21 dB, which is sufficiently small, when the phase value $\Delta\phi$ is 0.595 rad, and also the slope of loss is excellent in its linearity.

[0022]

In the first preferred embodiment, if the respective structural parameters of the first and second Mach-Zehnder interferometers 41, 42 are appropriately set such that the phase value $\Delta\phi$ becomes 0 when the temperatures of the main optical line 20 and second auxiliary optical line 22 are adjusted to a predetermined bias temperature by means of the heaters 51, 53, then the value of phase value $\Delta\phi$ can be changed within a range of from 0 rad to +0.595 rad when the temperatures of the main optical line 20 and second auxiliary optical line 22 are raised from the above-mentioned bias temperature, whereas the value of phase value $\Delta\phi$ can be changed within a range of from −0.595 rad to 0 rad when the temperatures of the main optical line 20 and second auxiliary optical line 22 is lowered from the above-mentioned bias temperature. When the value of phase value $\Delta\phi$ is thus changed within a range of from −0.595 rad to +0.595 rad, the slope of loss can be set within a range of from −5 dB/30 nm to

+5 dB/30 nm in a wavelength band of from 1535 nm to 1565 nm.

[0023]

Also, in the first preferred embodiment, when Peltier devices are provided instead of the heaters 51, 53 and the temperatures of the main optical line 20, the value of phase value $\Delta\phi$ can be set not only positive but also negative by raising or lowering the temperatures of the main optical line 20 and second auxiliary optical line 22. As in the foregoing, when the value of phase value $\Delta\phi$ is changed within the range of from −0.595 rad to +0.595 rad, the slope of loss can be set within the range of from −5 dB/30 nm to +5 dB/30 nm in the wavelength band of from 1535 nm to 1565 nm.

[0024]

Next, the second preferred embodiment of the optical filter 1 in accordance with the present preferred embodiment will be described. The second preferred embodiment was an optical filter having a wavelength band of 1.55 μm, that is, from 1535 nm to 1565 nm, a center wavelength of 1550 nm, and a maximum absolute value of 10 dB/30 nm in the slope of loss. In the second preferred embodiment, in the first Mach-Zehnder interferometer 41, the value of A is 0.85, the value of λ_0 was 1550 nm, and the value of $\Delta\lambda$ was 200 nm. Also, in the second Mach-Zehnder interferometer 42, the value of A was 0.60, the value of λ_0 was 1600 nm, and the value of $\Delta\lambda$ was 200 nm. Then, the respective temperatures of the main optical line 20 in the first Mach-Zehnder interferometer 41 and the second auxiliary optical line 22 in the second Mach-Zehnder interferometer 42 were adjusted by the heaters 51, 53, to make the respective values of phase value $\Delta\phi$ of the Mach-Zehnder interferometers 41, 42 have the same absolute

value with polarities opposite to each other to change the phase value $\Delta\phi$ within the range of 0 rad to 0.595 rad.

[0025]

Fig. 3 shows respective loss spectra with respect the phase value $\Delta\phi$ in the optical filter in accordance with the second preferred embodiment. As is clear from this graph, near the center wavelength of 1550 nm in the wavelength band of from 1535 nm to 1565 nm, loss is from 3.65 dB to 3.98 dB and thus is substantially constant. Also, it is seen that the slope of loss spectra can be set within the range of from 0 dB/30 nm to 10 dB/30 nm in the above-mentioned wavelength band. Also, the maximum value of a deviation from a straight line passing a point yielding a loss of 0.87 dB (loss at the center wavelength of 1550 nm) is $\pm$0.87 dB, which is sufficiently small, when the phase value $\Delta\phi$ is 0.314 rad, and also the slope of loss is excellent in its linearity.

[0026]

Also in the second preferred embodiment, if the respective structural parameters of the first and second Mach-Zehnder interferometers 41, 42 are appropriately set such that the phase value $\Delta\phi$ becomes 0 when the temperatures of the main optical line 20 and second auxiliary optical line 22 are adjusted to a predetermined bias temperature by means of the heaters 51, 53, then the value of phase value $\Delta\phi$ can be set not only positive but also negative by raising or lowering the temperatures of the main optical line 20 and second auxiliary optical line 22. Also, when Peltier devices are provided instead of the heaters 51, 53, the value of phase value $\Delta\phi$ can be set not only positive but also negative by raising or

lowering the temperatures of the main optical line 20 and second auxiliary optical line 22. As in the foregoing, when the value of phase value $\Delta\phi$ is changed within the range of from −0.595 rad to +0.595 rad, the slope of loss can be set within the range of from −10 dB/30 nm to +10 dB/30 nm in the wavelength band of from 1535 nm to 1565 nm.

[0027]

Next, the third preferred embodiment of the optical filter 1 in accordance with the present preferred embodiment will be described. The third preferred embodiment was an optical filter having a wavelength band of 1.59 μm, that is, from 1575 nm to 1605 nm, a center wavelength of 1590 nm, and a maximum absolute value of 5 dB/30 nm in the slope of loss. In the third preferred embodiment, in the first Mach-Zehnder interferometer 41, the value of A is 0.60, the value of λ_0 was 1590 nm, and the value of $\Delta\lambda$ was 200 nm. Also, in the second Mach-Zehnder interferometer 42, the value of A was 0.5, the value of λ_0 was 1640 nm, and the value of $\Delta\lambda$ was 200 nm. Then, the respective temperatures of the main optical line 20 in the first Mach-Zehnder interferometer 41 and the second auxiliary optical line 22 in the second Mach-Zehnder interferometer 42 were adjusted by the heaters 51, 53, to make the respective values of phase value $\Delta\phi$ of the Mach-Zehnder interferometers 41, 42 have the same absolute value with polarities opposite to each other to change the phase value $\Delta\phi$ within the range of from 0 rad to 0.595 rad.

[0028]

Fig. 4 shows respective loss spectra with respect the phase value $\Delta\phi$ in the optical filter of the third preferred embodiment.

As is clear from this graph, near the center wavelength of 1590 nm in the wavelength band of from 1575 nm to 1605 nm, loss is from 2.73 dB to 3.01 dB and thus is substantially constant. Also, it is seen that the slope of loss can be set within the range of from 0 dB/30 nm to 5 dB/30 nm in the above-mentioned wavelength band. Also, the maximum value of a deviation from a straight line passing a point yielding a loss of 2.89 dB (loss at the center wavelength of 1590 nm) is $\pm$0.21 dB, which is sufficiently small, when the phase value $\Delta\phi$ is 0.595 rad, and also the slope of loss is excellent in its linearity.

[0029]

Also in the third preferred embodiment, if the respective structural parameters of the first and second Mach-Zehnder interferometers 41, 42 are appropriately set such that the phase value $\Delta\phi$ becomes 0 when the temperatures of the main optical line 20 and second auxiliary optical line 22 are adjusted to a predetermined bias temperature by means of the heaters 51, 53, then the value of phase value $\Delta\phi$ can be set not only positive but also negative by raising or lowering the temperatures of the main optical line 20 and second auxiliary optical line 22. Also, when Peltier devices are provided instead of the heaters 51, 53, the value of phase value $\Delta\phi$ can be set not only positive but also negative by raising or lowering the temperatures of the main optical line 20 and second auxiliary optical line 22. As in the foregoing, when the value of phase value $\Delta\phi$ is changed within the range of from −0.595 rad to +0.595 rad, the slope of loss can be set within the range of from −5 dB/30 nm to +5 dB/30 nm in the wavelength band of from 1575 nm

to 1605 nm.

[0030]

As described above, in the optical filter 1 in accordance with the present preferred embodiment including the above-mentioned preferred embodiments, the loss in the predetermined wavelength in the predetermined wavelength band is substantially constant and the phase value $\Delta\phi$ is set by the temperature adjustment by the heaters 51, 53, and the slope of loss with respect to the wavelength in the wavelength band is set. In this manner, the optical filter 1 has a simple structure and easily controls the slope of loss as well. Also, the optical filter 1 is excellent in the linearity of its slope of loss. Further, since the optical filter 1 has individual constituents formed and integrated on the substrate 10, the optical filter 1 has a small size and a small number of components, and can be easily adjusted since optical axis adjustment is needed only at each of the optical entrance end 11 and the optical exit end 12.

[0031]

Also, without disposing the heater 51, a Peltier device may be disposed on the first auxiliary optical line 21 positioned between the first optical coupler 31 and the second optical coupler 32 to lower the temperature of the first auxiliary optical line 21 by means of the Peltier device. Alternatively, without providing the heater 53, a Peltier device may be disposed on the main optical line 20 positioned between the third optical coupler 33 and the fourth optical coupler 34 to lower the temperature of the main optical line 20 by means of the Peltier device. In either configuration, effects similar to those mentioned above are obtained.

[0032]

As a consequence, the optical filter 1 in accordance with the present preferred embodiment is suitable for a gain equalizer in an optical amplifier, for example. That is, if the loss in an optical transmission line positioned in front of an optical amplifier fluctuates for some reason, thereby causing the power of signal light entering the optical amplifier to fluctuate, then the optical amplifier changes its amplification gain in order to keep the power of the signal light emitted from the optical amplifier constant. If the amplification gain is changed as such, then the wavelength dependence of the gain, that is, a gain slope, fluctuates, whereby the flatness of the gain in the optical amplifier itself is lost. However, if the optical filter 1 in accordance with the present preferred embodiment is employed as a gain equalizer in the optical amplifier, and the phase value $\Delta\phi$ of the optical filter 1, that is, the slope of loss, is appropriately adjusted according to the optical power of the incident signal light, then the fluctuation in gain slope caused by the power fluctuation in the optical power of the incident signal light can be compensated by the slope of loss of the optical filter 1. Here, even when the slope of loss of the optical filter 1 is changed, the loss at the predetermined center wavelength in the signal light wavelength band would not fluctuate, whereby the S/N ratio of amplified signal light outputted from the optical amplifier would not deteriorate. In the case where the signal light wavelength band and the center wavelength are set, as in the above-mentioned preferred embodiments, in particular, the optical filter 1 in accordance with the present preferred embodiment is

suitable for a gain equalizer which equalizes the gain characteristic of an optical amplifier disposed in a repeater station or the like in an optical transmission system for transmitting signal light having a plurality of wavelengths in a wavelength band of 1.55 μm or in a wavelength band of 1.59 μm.

[0033]

(Second Preferred Embodiment)

Next, the second preferred embodiment of the optical filter in accordance with the present invention will be described. Fig. 5 is a view showing the configuration of the optical filter 2 in accordance with the second preferred embodiment. The optical filter 2 in accordance with the second preferred embodiment is different from the optical filter 1 in accordance with the first preferred embodiment in that it further includes a heater 52 as a first temperature regulating device in addition to the heater 51 and in that it further includes a heater 54 as a second temperature regulating device in addition to the heater 53.

[0034]

The heater 52 is disposed on the first auxiliary optical line 21 positioned between the first optical coupler 31 and the second optical coupler 32 to adjust the temperature of the first auxiliary optical line 21. The heater 52 adjusts, together with the heater 51, the optical path length difference between the main optical line 20 and the first auxiliary optical line 21 in the first Mach-Zehnder interferometer 41, to regulate the transmission characteristic T1(λ) of the first Mach-Zehnder interferometer 41. On the other hand, the heater 54 is disposed on the main optical line 20 positioned between

the third optical coupler 33 and the fourth optical coupler 34, to adjust the temperature of the main optical line 20. The heater 54 adjusts, together with the heater 53, the optical path length difference between the main optical line 20 and the second auxiliary optical line 22 in the second Mach-Zehnder interferometer 42, to regulate the transmission characteristic T2(λ) of the second Mach-Zehnder interferometer 42.

[0035]

Also in the present preferred embodiment, the respective transmission characteristics of the first and second Mach-Zehnder interferometers 41, 42 are represented by the above-mentioned formula (1), and the total loss spectrum L(λ) of the optical filter 2 is represented by the above-mentioned formula (2). If the respective values of constants A, λ_0, and $\Delta\lambda$ in the first Mach-Zehnder interferometer 41 and the second Mach-Zehnder interferometer 42 are appropriately designed, then the loss at a predetermined wavelength in a predetermined wavelength band is substantially constant, and the value of a phase value $\Delta\phi$ is set by the temperature adjustment effected by the heaters 51 to 54, whereby the slope of loss with respect to the wavelength is set in the wavelength band.

[0036]

In the present preferred embodiment, the phase value $\Delta\phi$ of the first Mach-Zehnder interferometer 41 is adjusted by the difference between the respective temperatures of the main optical line 20 and the first auxiliary optical line 21 set by means of the heaters 51, 52. For example, the phase value $\Delta\phi$ of the first Mach-Zehnder interferometer 41 increases if the temperature of the main optical

line 20 is raised by means of the heater 51, whereas the phase value $\Delta\phi$ of the first Mach-Zehnder interferometer 41 decreases if the temperature of the first auxiliary optical line 21 is raised by means of the heater 52.

[0037]

Similarly, the phase value $\Delta\phi$ of the second Mach-Zehnder interferometer 42 is adjusted by the difference between the respective temperatures of the main optical line 20 and the second auxiliary optical line 22 set by means of the heaters 53, 54. For example, the phase value $\Delta\phi$ of the second Mach-Zehnder interferometer 42 increases if the temperature of the second auxiliary optical line 22 is raised by means of the heater 53, whereas the phase value $\Delta\phi$ of the second Mach-Zehnder interferometer 42 decreases if the temperature of the main optical line 20 is raised by means of the heater 54.

[0038]

Namely, the optical filter 2 in accordance with the present preferred embodiment is designed such that, when none of the heaters 51 to 54 carries out temperature adjustment, the phase value $\Delta\phi$ becomes a predetermined value $\Delta\phi_0$ (for example, $\Delta\phi_0 = 0$), whereby the slope S of loss becomes a predetermined value S_0 (for example, $S_0 = 0$). Here, without carrying out the temperature adjustment by the heaters 52, 54, the phase value $\Delta\phi$ can be changed within the range of $\Delta\phi > \Delta\phi_0$ by adjusting the temperatures of the main optical line 20 in the first Mach-Zehnder interferometer 41 and the second auxiliary optical line 22 in the second Mach-Zehnder interferometer 42 by the heaters 51, 53, whereby the slope S of loss spectrum can be changed within the range of $S > S_0$. Conversely, without carrying

out the temperature adjustment by the heaters 51, 53, the phase value $\Delta\phi$ can be changed within the range of $\Delta\phi < \Delta\phi_0$ by adjusting the temperatures of the first auxiliary optical line 21 in the first Mach-Zehnder interferometer 41 and the main optical line 20 in the second Mach-Zehnder interferometer 42 by way of the heaters 52, 54, whereby the slope S of loss can be changed within the range of $S < S_0$.

[0039]

In the optical filter 2 in accordance with the second preferred embodiment, as in the foregoing, the phase value $\Delta\phi$, that is, the slope of loss spectrum, can be set to 0 when the temperature adjustment is not carried out by means of any of the four heaters 51 to 54, whereas the phase value $\Delta\phi$, that is, the slope of loss spectrum, can be set not only positive but also negative by the temperature adjustment carried out by two heaters alone selected from the four heaters 51 to 54. Therefore, the optical filter 2 in accordance with the second preferred embodiment is preferable in that it not only exhibits effects similar to those exhibited by the optical filter 1 in accordance with the first preferred embodiment, but also makes it possible to suppress its power consumption more as compared with the case where the phase value $\Delta\phi$ is set to 0 at a predetermined bias temperature in the optical filter 1 in accordance with the first preferred embodiment.

[0040]

Peltier devices can be employed in place of the heaters 51 to 54 in the second preferred embodiment as well. In this case, the phase value $\Delta\phi$, that is, the slope of loss spectrum, can be set

not only positive but also negative by raising one of the temperature of the main optical line 20 in the first Mach-Zehnder interferometer 41 or the temperature of the second auxiliary optical line 22 in the second Mach-Zehnder interferometer 42 and lowering the other, and by raising one of the temperature of the first auxiliary optical line 21 in the first Mach-Zehnder interferometer 41 and the temperature of the main optical line 20 in the second Mach-Zehnder interferometer 42 and lowering the other, for example. This case is also preferable in that it can suppress the power consumption to a low level.

[0041]

The present invention is not restricted to the preferred embodiments described above, but various modifications are possible therein. For example, in the optical filter in accordance with the present invention, it is not always necessary for individual constituents to be integrated on a substrate, but each of the first optical line, the first auxiliary optical line, and the second auxiliary optical line may be made of an optical fiber, whereas each of the first to fourth optical couplers may be made of an optical fiber coupler. This case is preferable in that insertion loss decreases when the optical filter is disposed on the optical fiber transmission line.

[0042]

[Effects of the Invention]

In accordance with the present invention, as described in detail, the respective transmission characteristics of the first and second Mach-Zehnder interferometers cascaded to each other while sharing the main optical line are regulated by the temperature adjustment

effected by the first and second temperature regulating devices, whereby the slope of loss of light with respect to wavelength in the above-mentioned wavelength band is set with the loss of light between the optical entrance end and the optical exit end in the predetermined wavelength in the predetermined wavelength band kept substantially constant. Thus, the optical filter in accordance with the present invention has a simple structure and can easily control the slope of loss. As a consequence, this optical filter is suitably used as a gain equalizer or the like in an optical amplifier, for example. Even if a slope occurs in a gain due to the fact that the amplification gain of an optical amplifier fluctuates according to the fluctuation of incident signal light, the optical filter can compensate for this gain slope. Also, even when the slope of loss of the optical filter is changed, the loss at the center wavelength is substantially kept constant and thus the S/N ratio of the signal light would not deteriorate.

[0043]

Also, in the case where the temperature of one of the main optical line and the first auxiliary optical line, which are positioned between the first optical coupler and the second optical coupler, is adjusted by means of the first temperature regulating device and where the temperature of one of the main optical line and the second auxiliary optical line, which are positioned between the third optical coupler and the fourth optical coupler, is adjusted by means of the second temperature regulating device, it is only necessary that one piece of heater, Peltier device, or the like be provided as the first temperature regulating device, and that one piece of heater, Peltier

device, or the like be provided as the second temperature regulating device, whereby a simpler configuration can be realized. In particular, in the case where the temperature of the main optical line positioned between the first optical coupler and the second optical coupler is adjusted while the temperature of the second auxiliary optical line positioned between the third optical coupler and the fourth optical coupler is adjusted, both of them can be subjected to the same temperature adjustment (for example, temperature is raised or lowered in both of them), whereby the temperature adjustment can be further easily realized.

[0044]

Also, in the case where the temperature of both of the main optical line and the first auxiliary optical line, which are positioned between the first optical coupler and the second optical coupler, is adjusted by means of the first temperature regulating device, whereas the temperature of both of the main optical line and the second auxiliary optical line, which are positioned between the third optical coupler and the fourth optical coupler, is adjusted by means of the second temperature regulating device, two pieces of heaters, Peltier devices, or the like are provided as the first temperature regulating device, whereas two pieces of heaters, Peltier devices, or the like are provided as the second temperature regulating device. Here, when no temperature adjustment is carried out by means of any of the four heaters, the slope of loss can be set to a predetermined value. Also, the slope of loss can be set not only positive but also negative by temperature adjustment carried out by two heaters or the like selected from the four heaters or the like alone. As a

consequence, it is preferable in that power consumption is low.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is a view showing the configuration of an optical filter in accordance with the first embodiment.

[Fig. 2]

Fig. 2 is a spectrum chart in which loss spectra of an optical filter in accordance with the first embodiment are shown for respective values of phase value $\Delta\phi$.

[Fig. 3]

Fig. 3 is a spectrum chart in which loss spectra of an optical filter in accordance with the second embodiment are shown for respective values of phase value $\Delta\phi$.

[Fig. 4]

Fig. 4 is a spectrum chart in which loss spectra of an optical filter in accordance with the third embodiment are shown for respective values of phase value $\Delta\phi$.

[Fig. 5]

Fig. 5 is a view showing the configuration of an optical filter in accordance with the second embodiment.

[Description of the Reference Characters]

1,2 ... optical filter, 10 ... substrate, 11 ... optical entrance end, 12 ... optical exit end, 20 ... main optical line, 21 ... first auxiliary optical line, 22 ... second auxiliary optical line, 31 ... first optical coupler, 32 ... second optical coupler, 33 ... third optical coupler, 34 ... fourth optical coupler, 41 ... first Mach-Zehnder interferometer, 42 ... second Mach-Zehnder

interferometer, 51,52 ... heater (first temperature regulating device), 53,54 ... heater (second temperature regulating device)

[Name of Document] ABSTRACT

[Abstract]

[Purpose] It is the object of the present invention to provide an optical filter which is preferably used as a gain equalizer in an optical amplifier, has a simple structure, and can easily control the slope of loss.

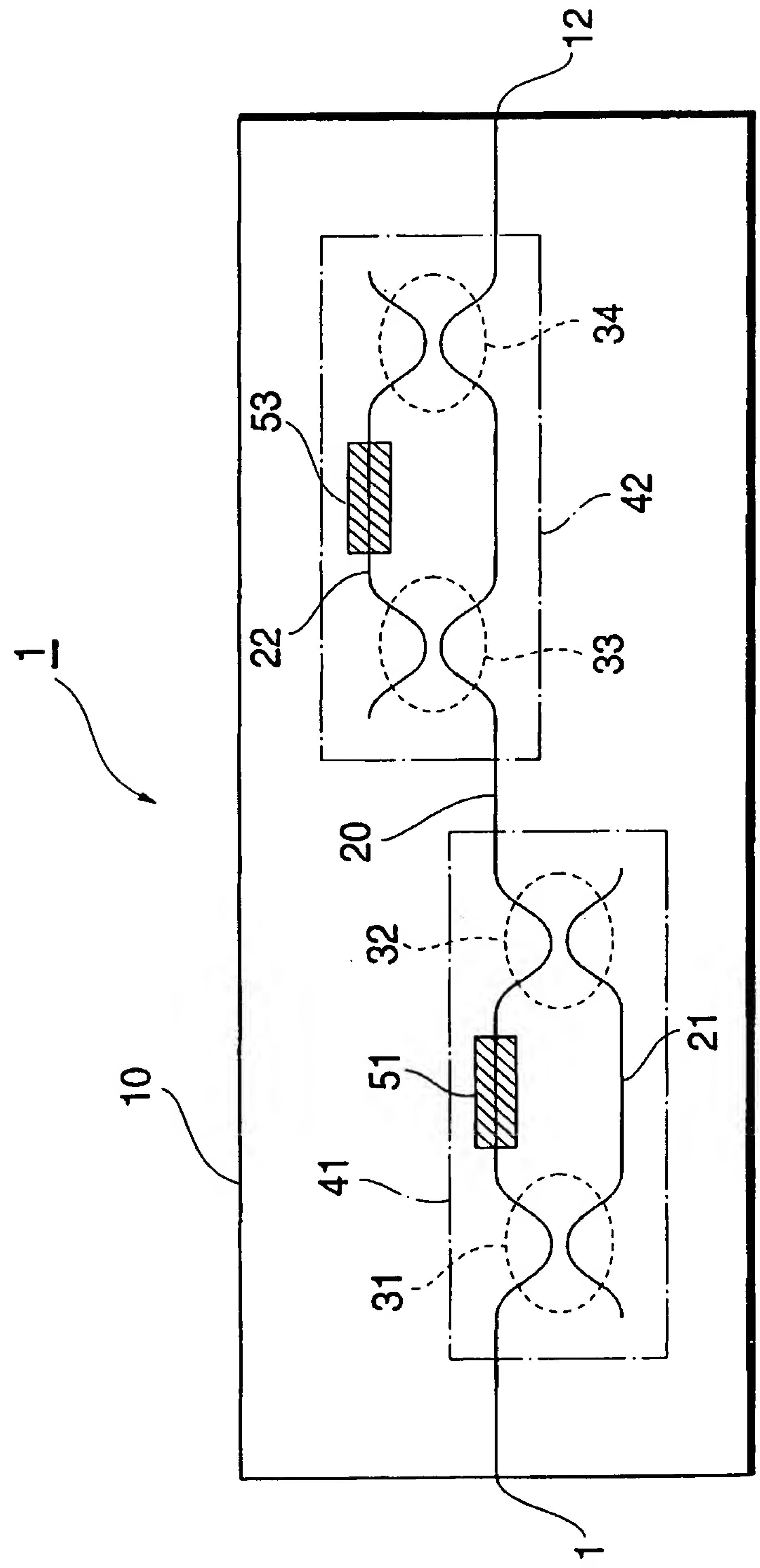
[Solving Means] A first Mach-Zehnder interferometer 41 is constituted by a main optical line 20, a first auxiliary optical line 21, a first optical coupler 31, and a second optical coupler 32. A second Mach-Zehnder interferometer 42 is constituted by the main optical line 20, a second auxiliary optical line 22, a third optical coupler 33, and a fourth optical coupler 34. The temperature of main optical line 20 positioned between the first optical coupler 31 and the second optical coupler 32 is adjusted by a heater 51. The temperature of main optical line 20 positioned between the third optical coupler 33 and the fourth optical coupler 34 is adjusted by a heater 53. In the optical filter 1, the loss of light entering an optical entrance end 11 and emitted from an optical exit end 12 in the predetermined wavelength in the predetermined wavelength band is kept substantially constant, whereby the slope of loss with respect to wavelength in the above-mentioned wavelength band is set.

SE00-0136-00AU

【書類名】　　図面

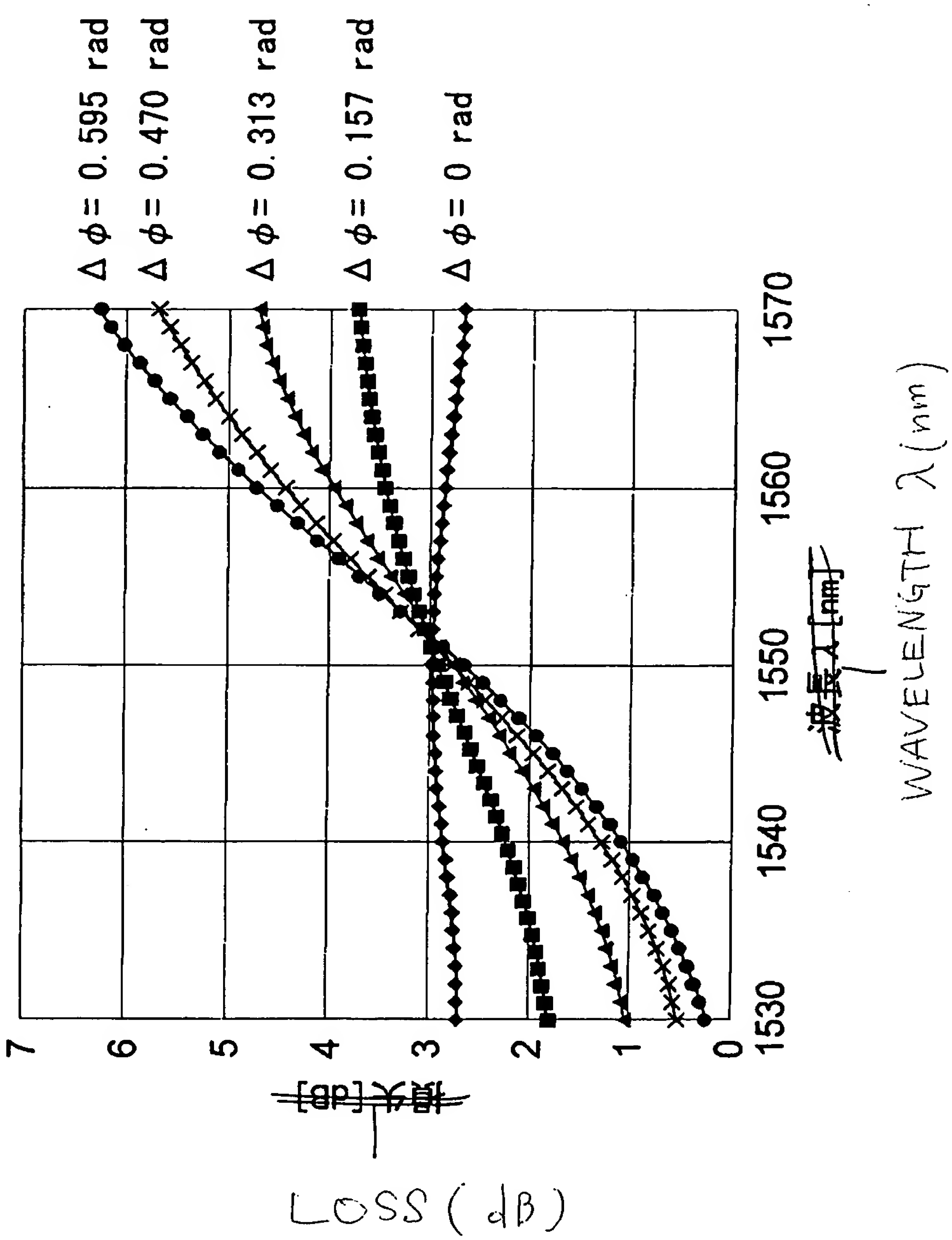
~~【図１】~~

FIG. 1



~~【図２】~~

FIG.2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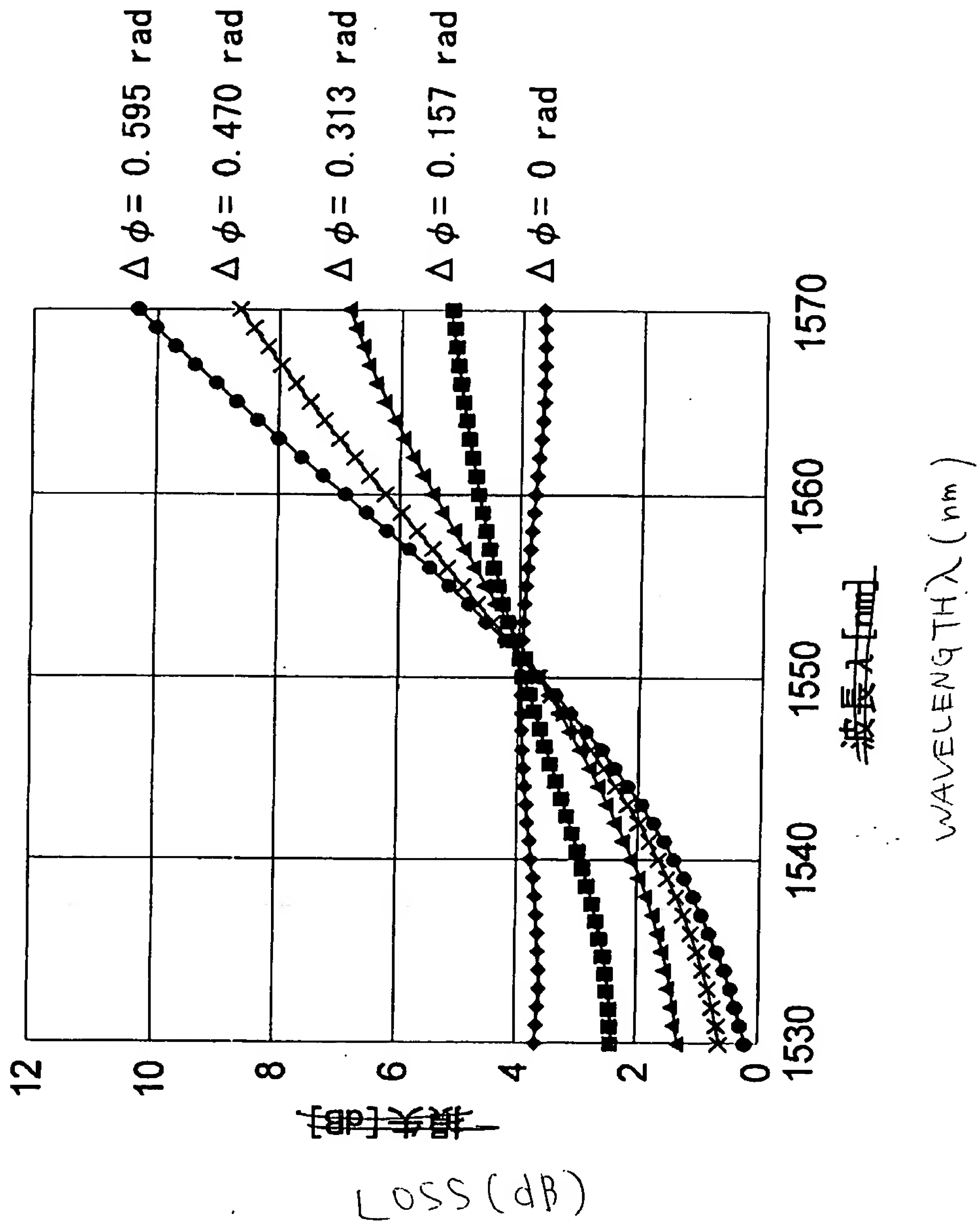
1540
1550
1560
1570
~~波長λ[nm]~~
WAVELENGTH λ(nm)
0
1
2
3
4
5
6
7
~~損失[dB]~~
LOSS (dB)

~~【図３】~~

FIG. 3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1530
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1550
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1570
~~波長λ[nm]~~
WAVELENGTH λ (nm)
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2
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6
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10
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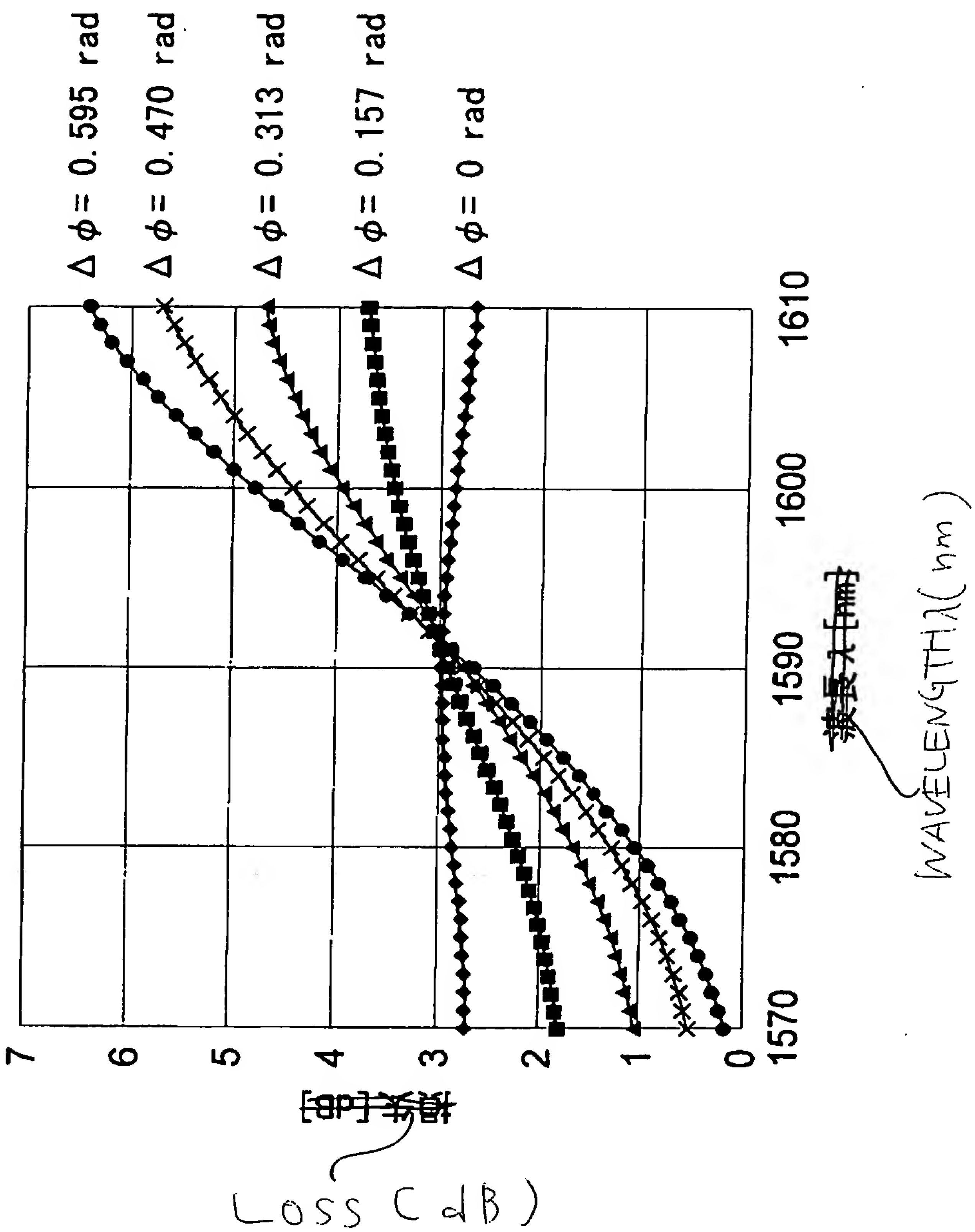
~~損失[dB]~~
LOSS (dB)

~~【図４】~~

Fig.4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1580
1590
1600
1610
~~波長λ[nm]~~
WAVELENGTH λ (nm)
0
1
2
3
4
5
6
7
~~損失[dB]~~
LOSS (dB)

~~【図５】~~

FIG. 5